

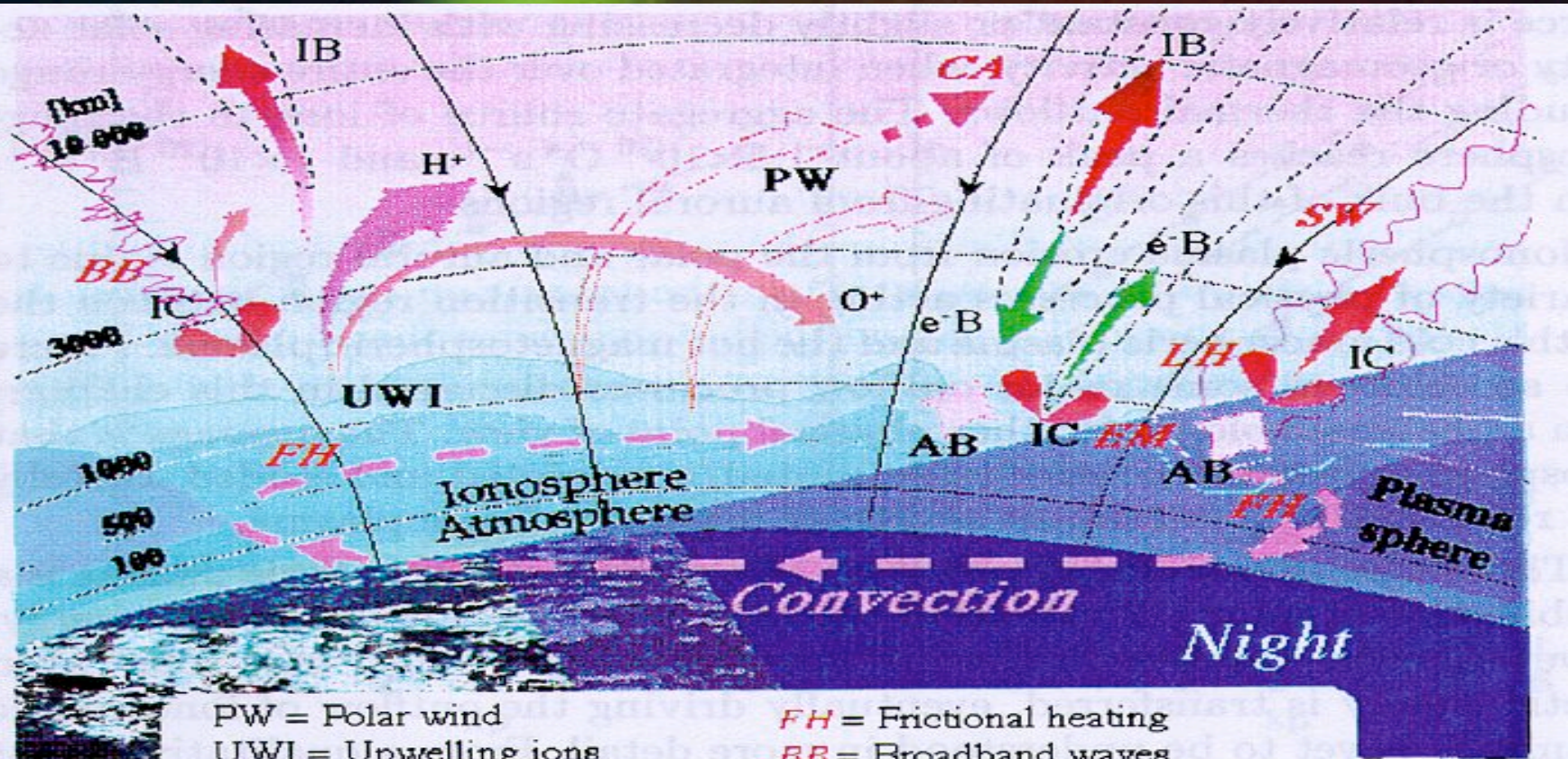
New formula representations of high-latitude O^+ ionospheric outflows for use in global magnetospheric modeling

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High-latitude Ionosphere



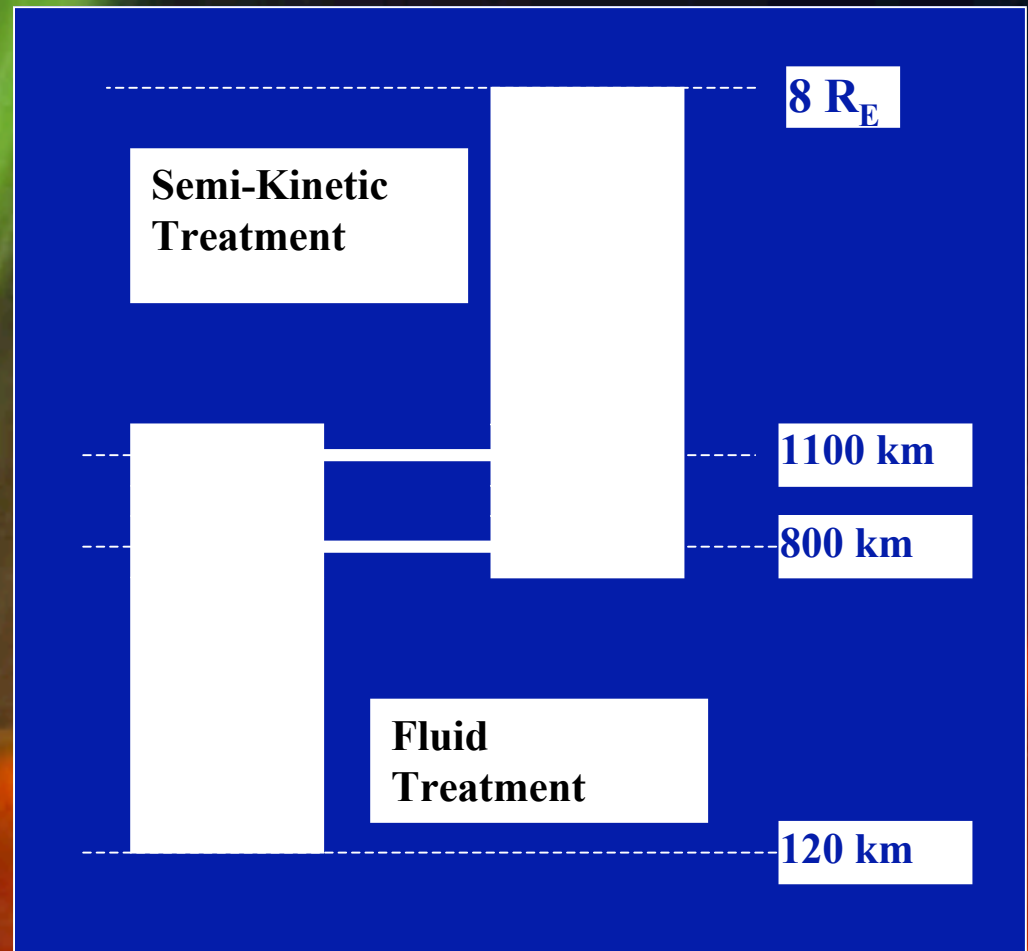
PW = Polar wind
 UWI = Upwelling ions
 IC = Ion conics
 IB = Ion beams
 AB = Auroral bulk upflow
 e⁻B = Electron beams

FH = Frictional heating
 BB = Broadband waves
 LH = Lower hybrid waves
 EM = Ion cyclotron waves
 SW = Solitary Kin. Alfvén waves
 CA = Centrifugal acceleration

- Flux tube extends from 120 km to several R_E altitude.

- Fluid-region upper boundary conditions for successive steps from advancing GSK treatment.

- Lower boundary of GSK treatment set at 800 km altitude. Simulation H^+ and O^+ ions injected at lower boundary of GSK based on fluid-treatment results there.



The dynamic boundary coupling in an overlap region between the fluid and generalized semi-kinetic treatments in the DyFK model [after Estep et al., 1999]

Strangeway et al.[2005] analysis of FAST particle and field observations at 4000 km altitude:

Ion flux correlated with electron precipitation:

$$f_i = 1.022 \times 10^{9 \pm 0.341} n_{ep}^{2.200 \pm 0.489}$$

where f_i is the ion flux in $\text{cm}^{-2}\text{s}^{-1}$ and n_{ep} is precipitating electron density.

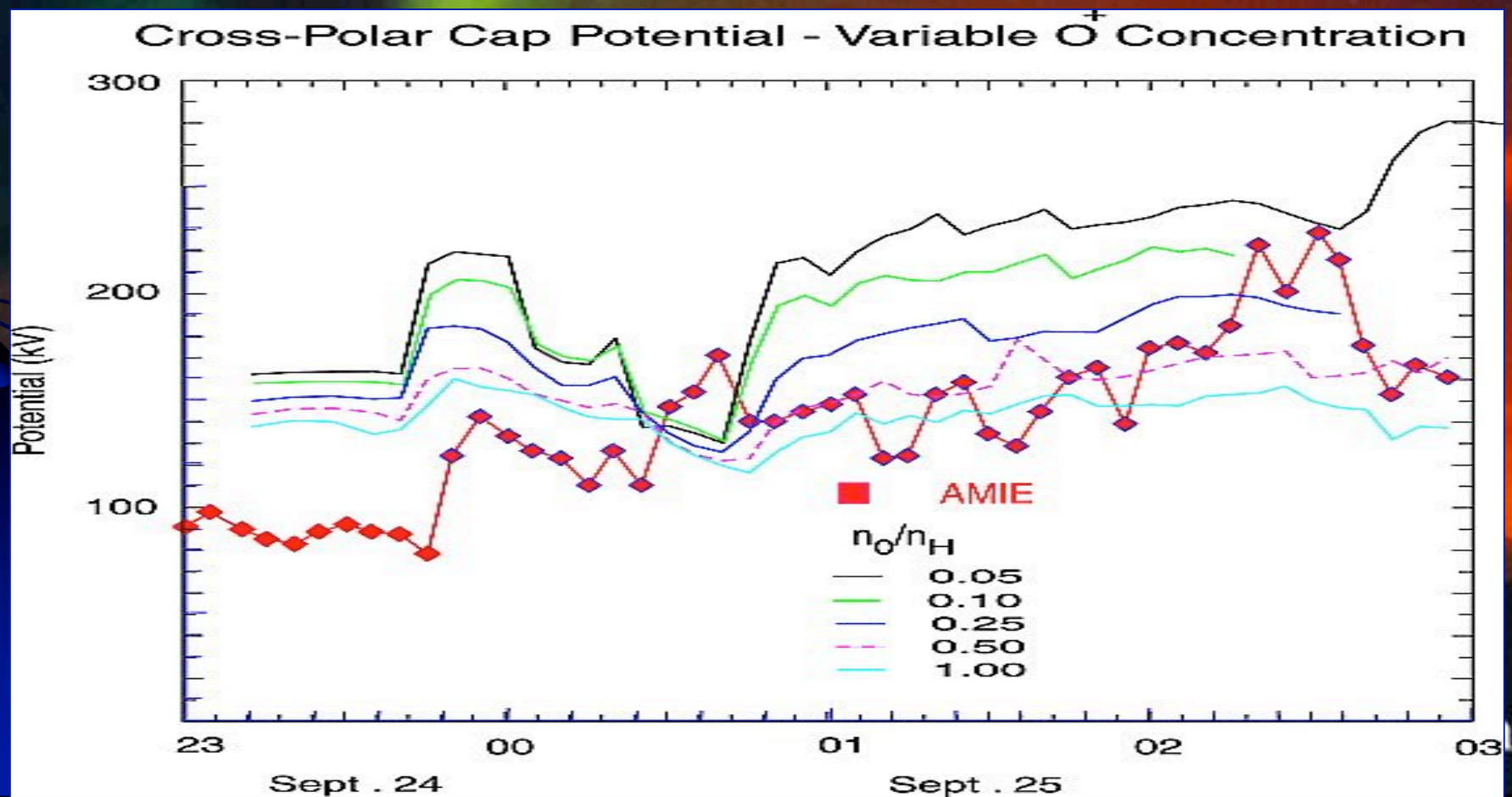
Correlation with Poynting flux:

$$f_i = 2.142 \times 10^{7 \pm 0.242} S^{1.265 \pm 0.445}$$

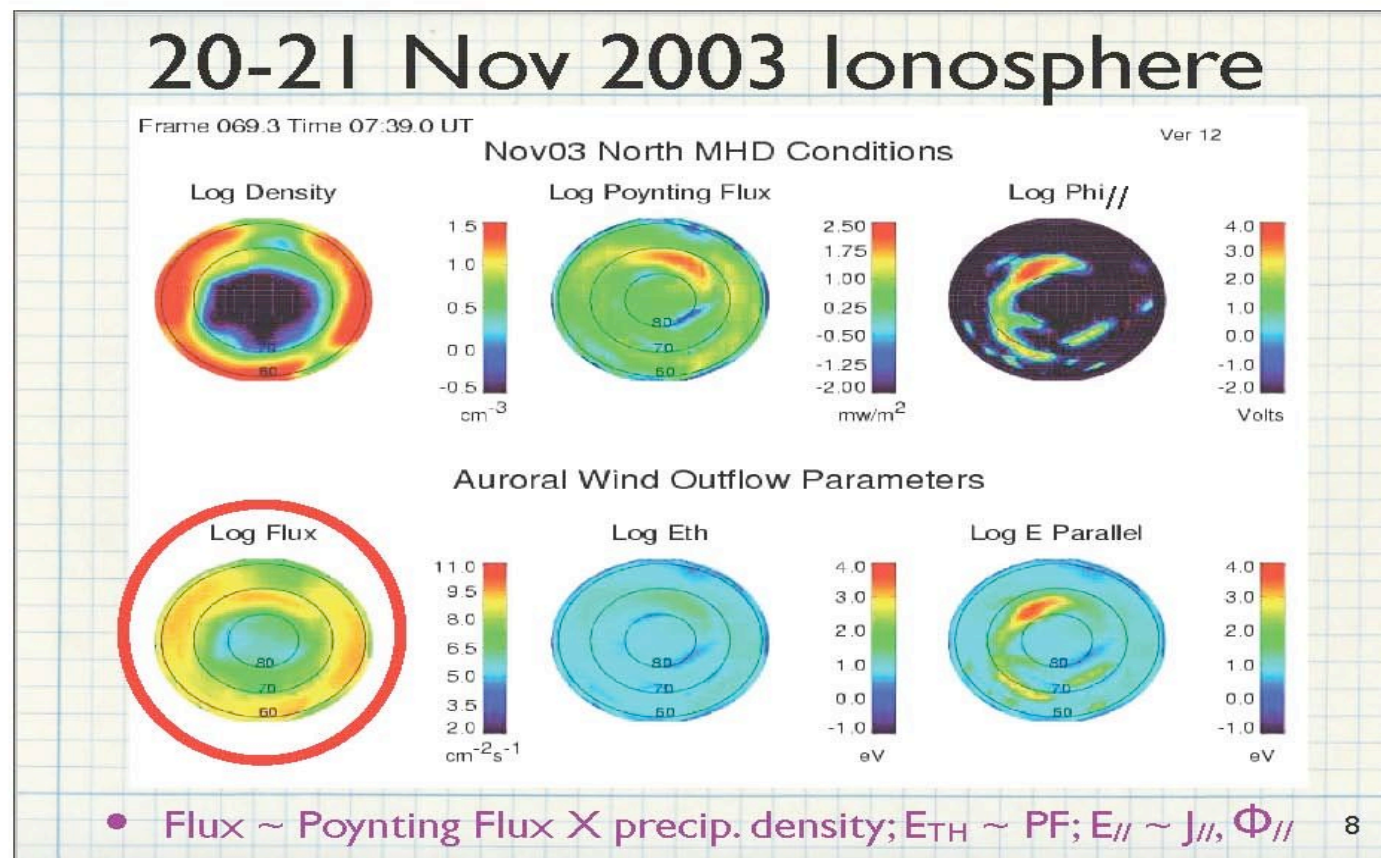
where S is the Poynting flux at 4000 km altitude in $\text{mW}\cdot\text{m}^{-2}$.

Somewhat similar analysis by Zheng et al.[2005] with POLAR observations near 6000 km altitude.

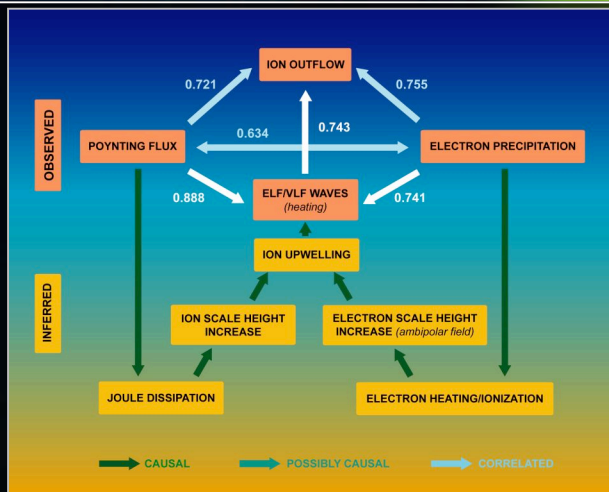
Winglee et al. [JGR, 2002]: Global impact of ionospheric outflows on the dynamics of the magnetosphere and cross-polar cap potential



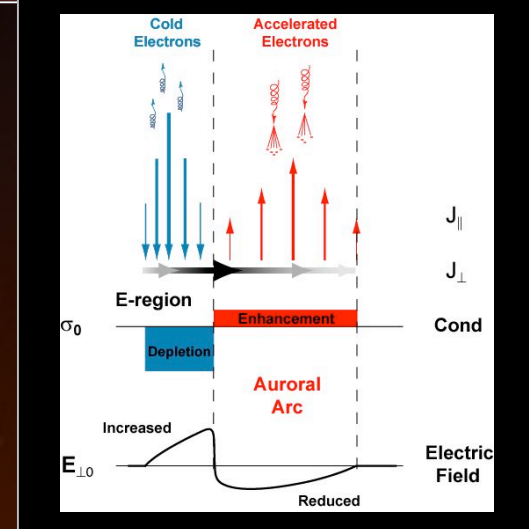
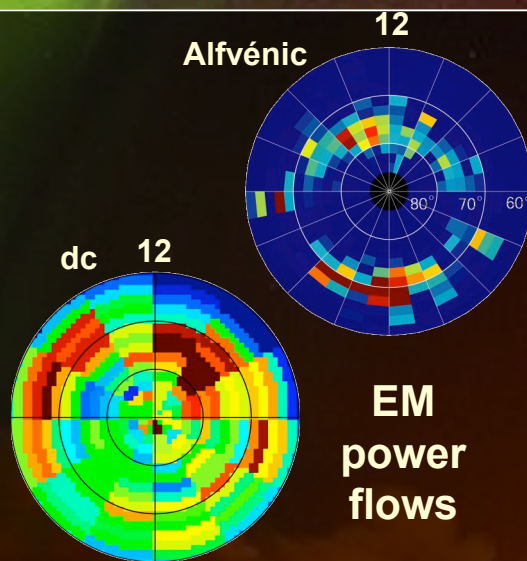
Moore et al.[2007]: Use of Strangeway et al. formula for ionospheric ion trajectory based global modeling—input parameters provided by MHD model



From Lotko et al.: How do ionospheric outflows impact magnetosphere-ionosphere system dynamics?

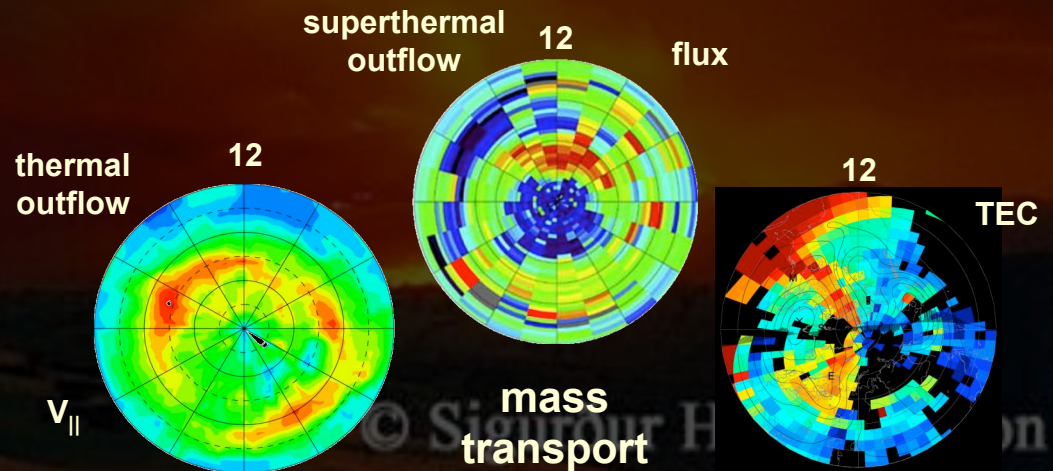
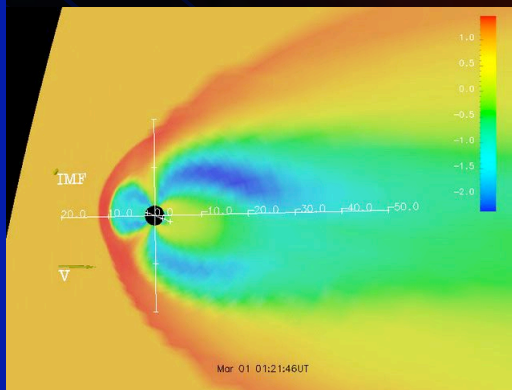


electrodynamic–inertial linkage

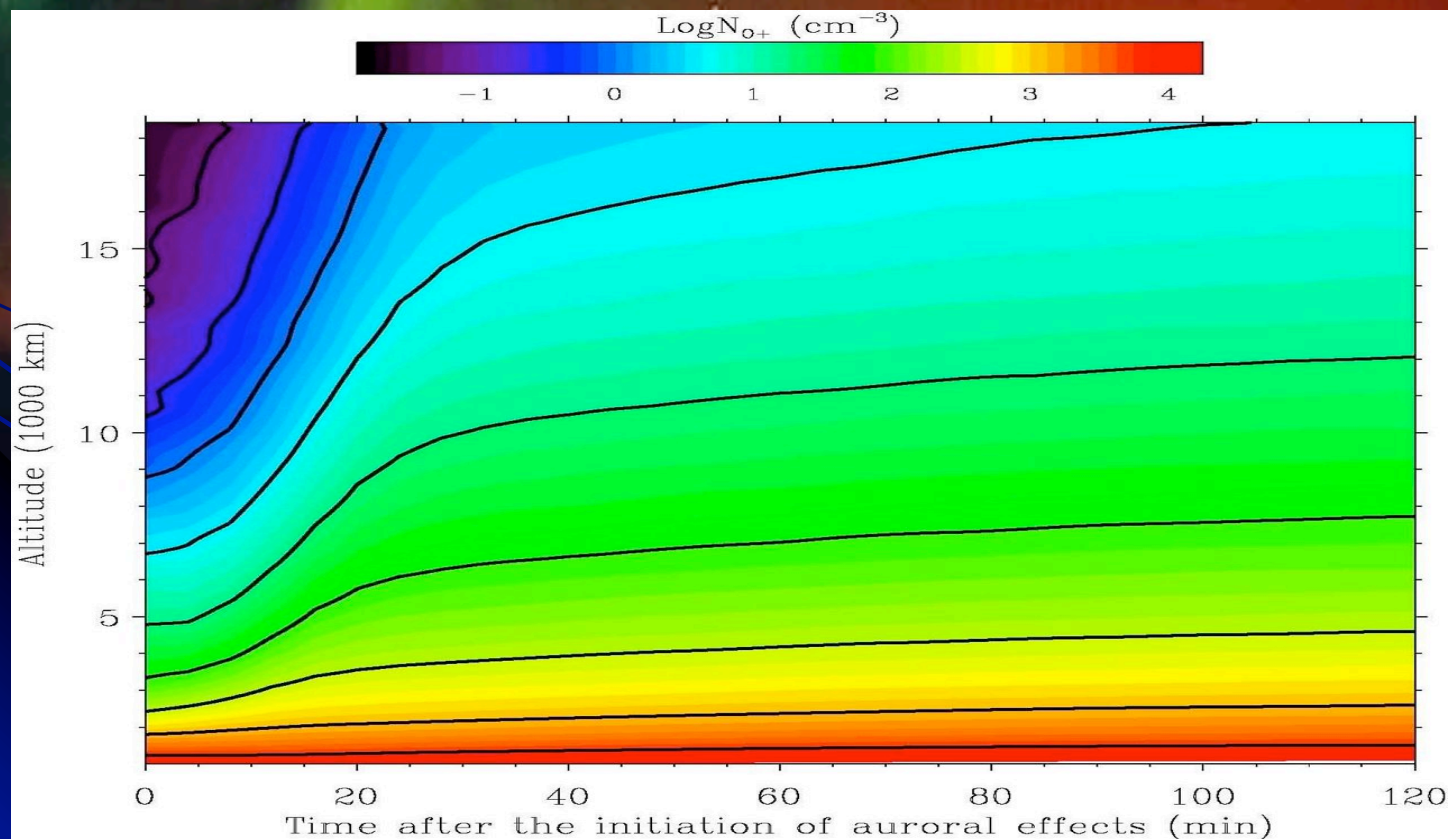


coupling and feedback

global modeling

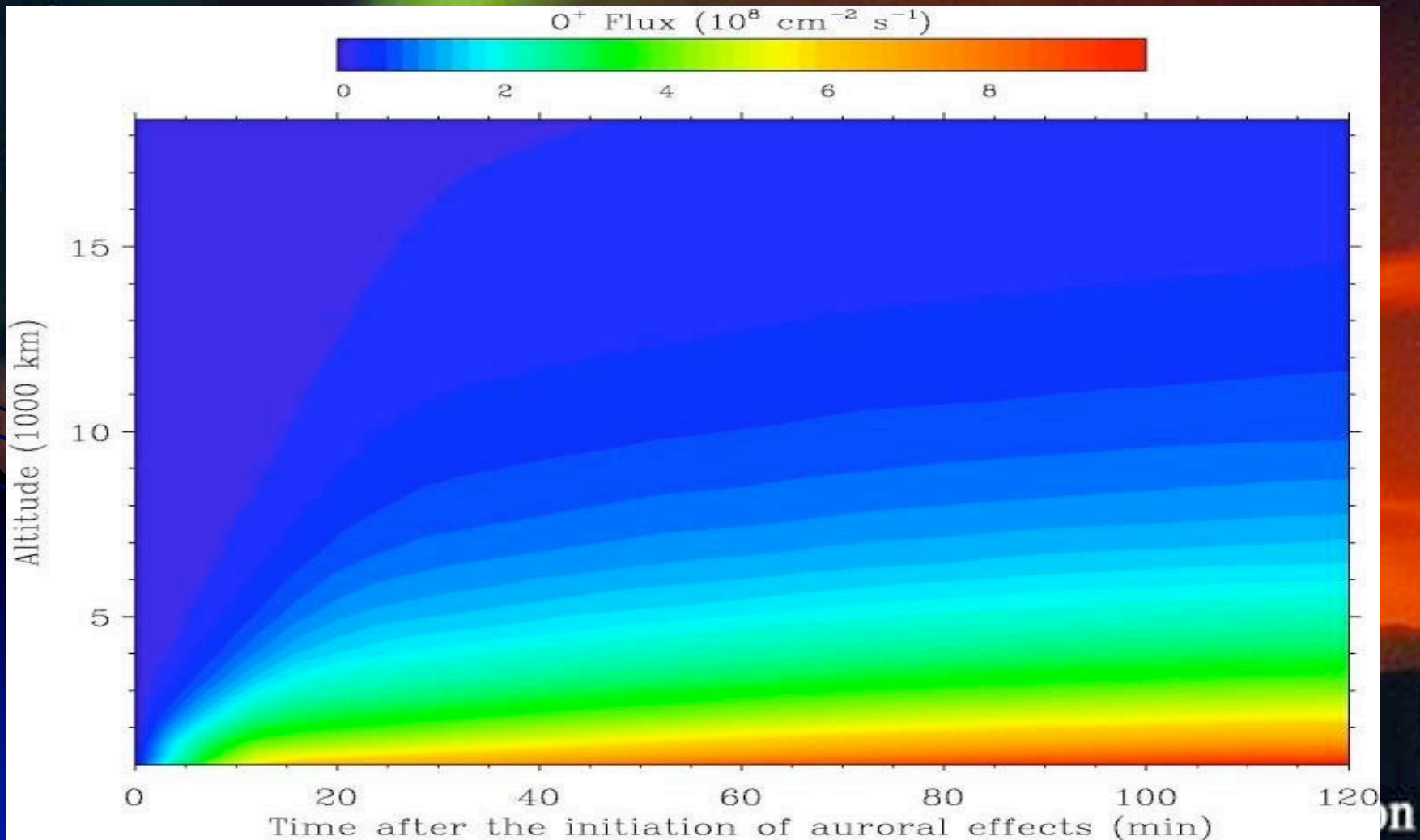


To obtain an appropriate formula representation based on DyFK simulations, 924 DyFK runs were used to obtain the O^+ outflux at $3 R_E$ altitude in a flux tube (as then mapped to 1000 km altitude) subjected to the two indicated auroral processes for two hours. The evolution of the O^+ density for a typical run is displayed here.



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Evolution of the O^+ field-aligned flux profile for the same DyFK simulation run.



O⁺ Outflows versus Wave Spectral Level and Electron Precipitation Parameters based on DyFK Runs

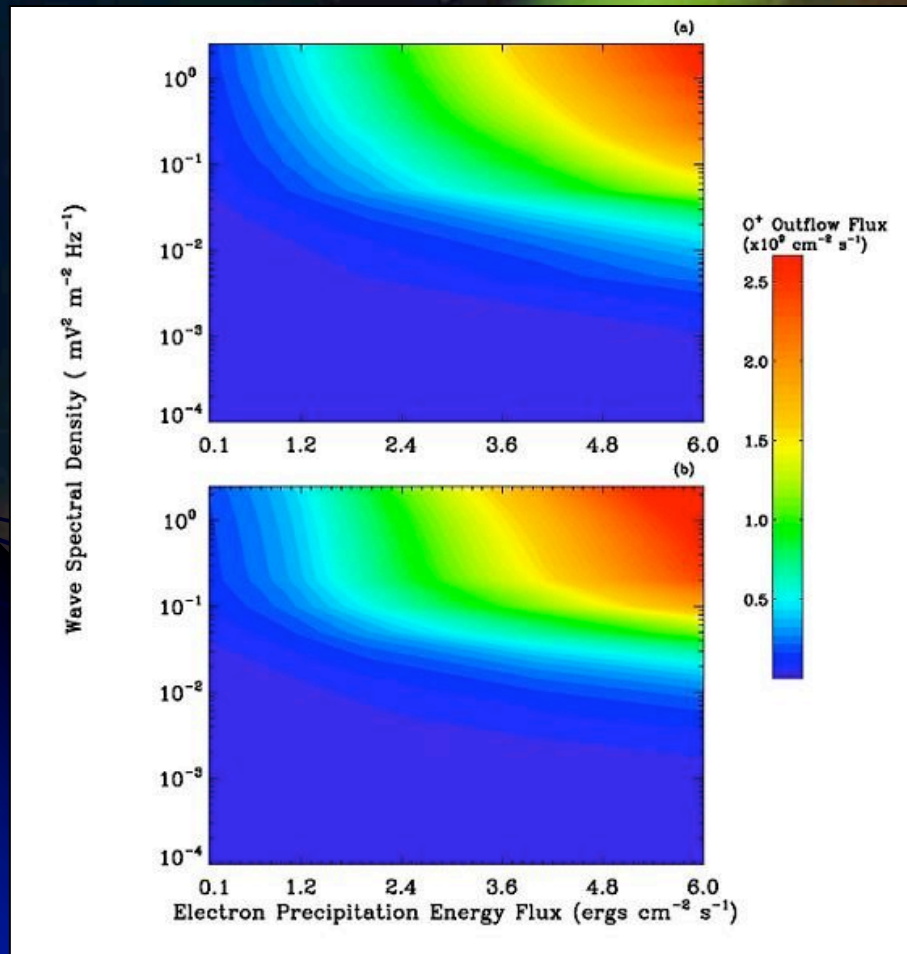
From DyFK simulations for various parameters of wave spectral density, soft electron precipitation energy flux, and characteristic electron precipitation energy we obtained O⁺ outflow dependences (next slides) which may be approximately represented by the formula representing the O⁺ outflows:

$$Flux_{O^+} = (3.1 \times 10^6 + 10^8 f_e^{0.2})$$
$$(\tanh(10D_{wave}) + 0.2D_{wave}^{0.6}) e^{\left(\frac{500 - E_n}{500 - Z}\right)^{2.6}} + 5.0 \times 10^6$$

$$\text{where } Z = 160 f_e^{0.2} (1 - e^{-f_e^{1.4}})$$

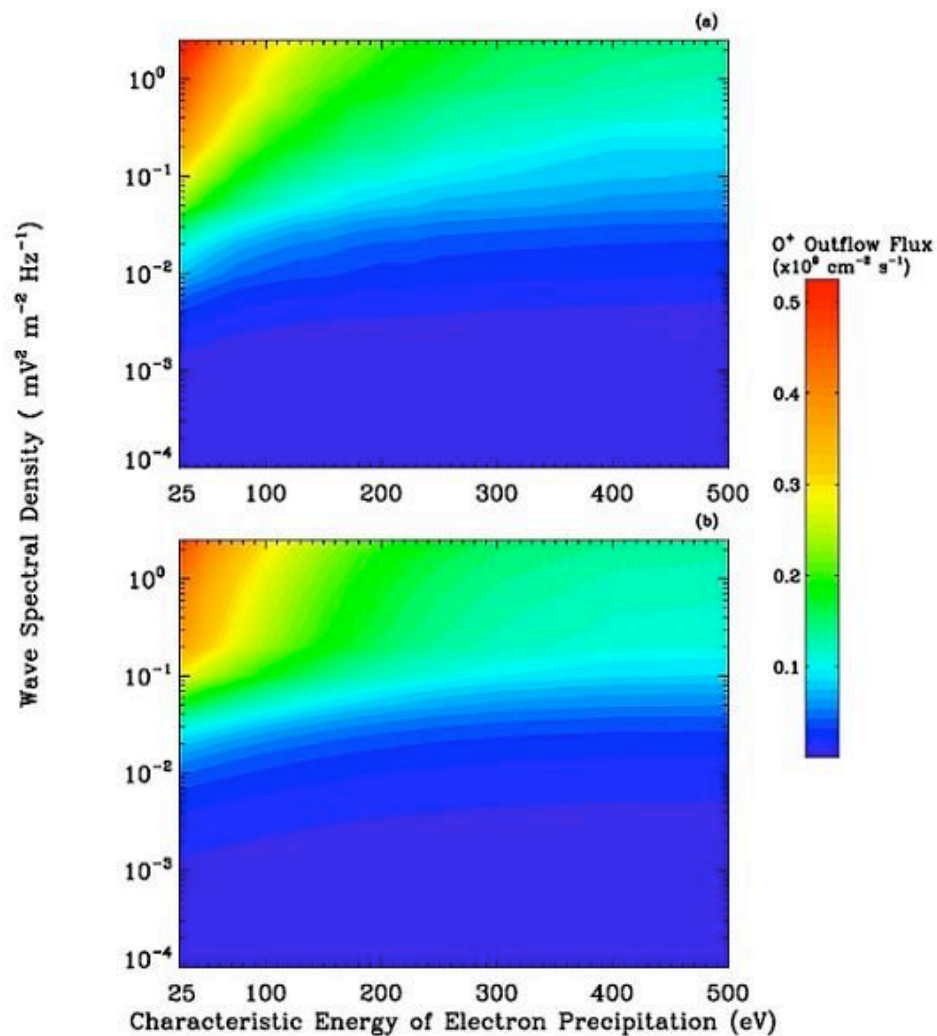
where Flux_{O⁺} is the O⁺ number flux in cm⁻² s⁻¹ at 3 R_E mapped to 1000 km altitude; f_e is the electron precipitation energy flux in ergs cm⁻² s⁻¹, and D_{wave} is the wave spectral density at 6.5 Hz in (mV)² m⁻² Hz⁻¹, E_n is the characteristic energy of the electron precipitation.

Comparison of DyFK simulation results with empirical formula representation



The top panel displays a spectrogram of the O^+ outflows versus the wave spectral density-electron precipitation energy flux from the DyFK simulations, while the bottom panel is the O^+ outflow spectrogram represented by the formula presented on the previous slide. These spectrogram “cuts” are for a fixed characteristic electron precipitation energy of 100 eV.

Comparison of DyFK simulation results with empirical formula representation (continued)



Here the top panel displays a spectrogram of the O^+ outflows versus the wave spectral density and electron precipitation characteristic energy from the DyFK simulations, while the bottom panel is the O^+ outflow spectrogram represented by the formula presented on the earlier slide. These spectrogram “cuts” are for a fixed electron precipitation energy flux of $0.7 \text{ ergs cm}^{-2} \text{ s}^{-1}$.

Summary of Results for Formula Representation

The wave heating process functions as a kind of “valve” on the net O^+ outflux. If heating is insufficient, the produced outflux is limited. If wave spectral density exceeds a certain threshold which causes energization of majority of the entering O^+ ions to escape energies, further increases of wave spectral density cause no significant further increase in O^+ (number) outflux.

► However, increases in electron precipitation cause ~ monotonic increases of O^+ outflux.

Observational evidence for wave-heating “valve” effect?

Knudsen et al[1998] examined Freja measurements, at ~1700 km altitude, for correlations between ion energization and electron bursts and BBELF waves. The plot at the right displays integrated 0-20 eV ion counts versus wave spectral density which suggest that significant local heating occurs only above a critical wave spectral density level. This is, however, somewhat different than the “valve” question of attainment of significant escape fluxes of O^+ requiring such a threshold in wave power.

